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Metke et al.

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(54) **METHODS AND SYSTEMS FOR MAINTAINING ROUTING TABLES IN AN AD-HOC WIRELESS NETWORK**

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H04W 40/24	(2009.01)
H04W 84/18	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 40/248*** (2013.01); *H04W 84/18* (2013.01)

(58) **Field of Classification Search**

CPC H04W 40/248; H04W 84/18; H04W 28/021

See application file for complete search history.

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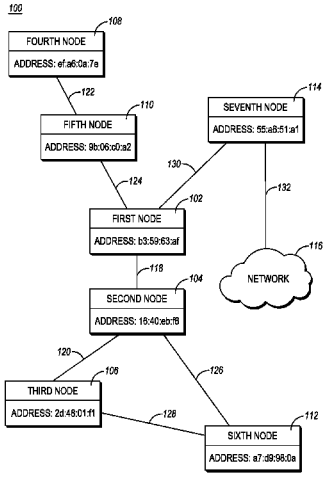
Primary Examiner — Melanie Jagannathan

(57) **ABSTRACT**

Disclosed herein are methods and systems for maintaining routing tables in an ad-hoc wireless network. In an embodiment, a first node receives, from a second node having a second network address, a first data packet having a third network address as the source address and a fourth network address as the destination address. The first node determines that its server routing table (i) contains a stored server route to the fourth network address and (ii) does not contain a server route to the third network address, and responsively adds, to its server-to-client routing table, a server-to-client route to the third network address with the second network address as the associated next hop. The first node transmits, to the second node at the second network address, a second data packet that has the third network address as the destination address.

20 Claims, 8 Drawing Sheets



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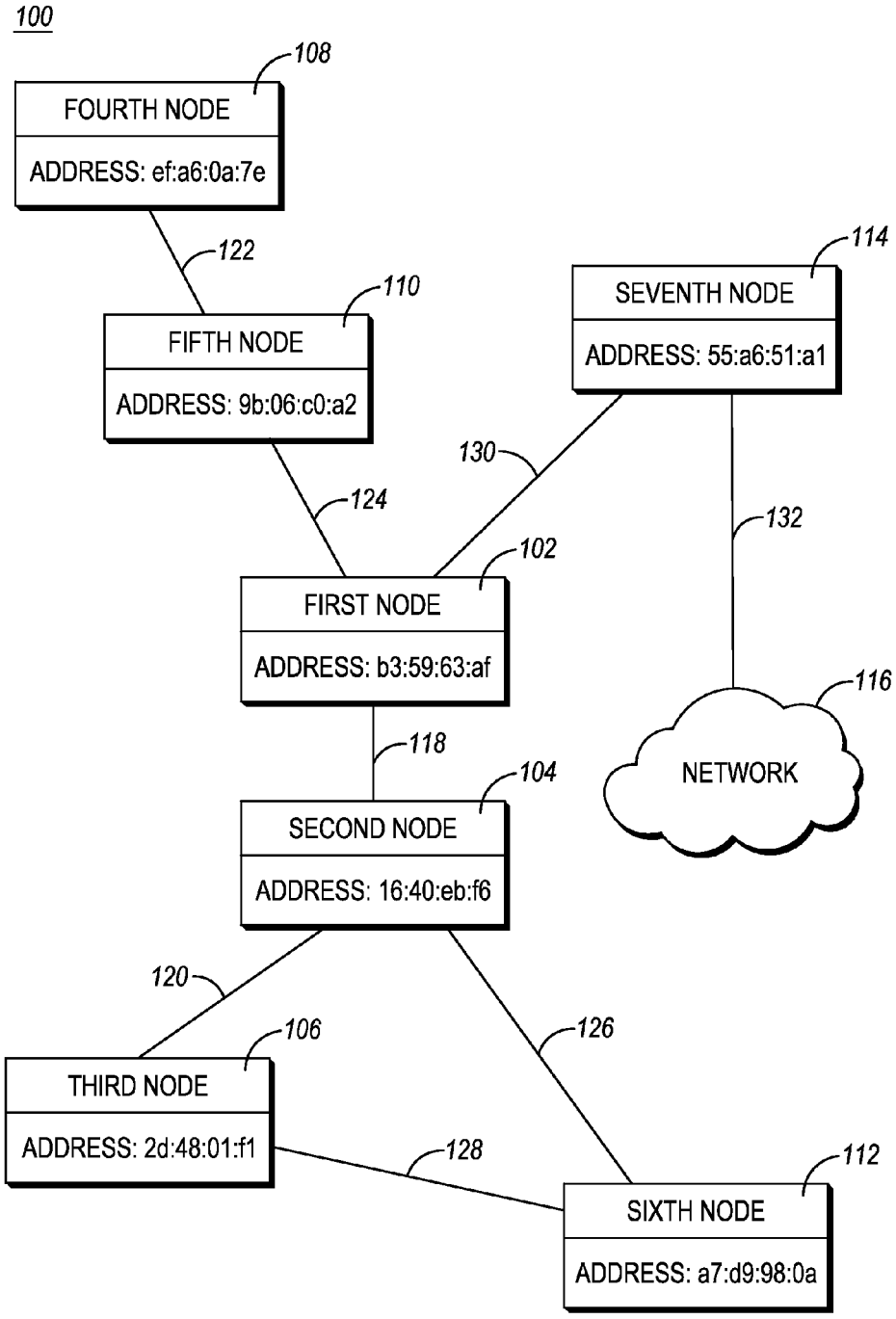
100
108
FOURTH NODE
ADDRESS: ef:a6:0a:7e
122
110
FIFTH NODE
ADDRESS: 9b:06:c0:a2
114
SEVENTH NODE
ADDRESS: 55:a6:51:a1
130
124
132
102
FIRST NODE
ADDRESS: b3:59:63:af
116
NETWORK
118
104
SECOND NODE
ADDRESS: 16:40:eb:f6
120
106
126
THIRD NODE
ADDRESS: 2d:48:01:f1
128
112
SIXTH NODE
ADDRESS: a7:d9:98:0a

FIG. 1

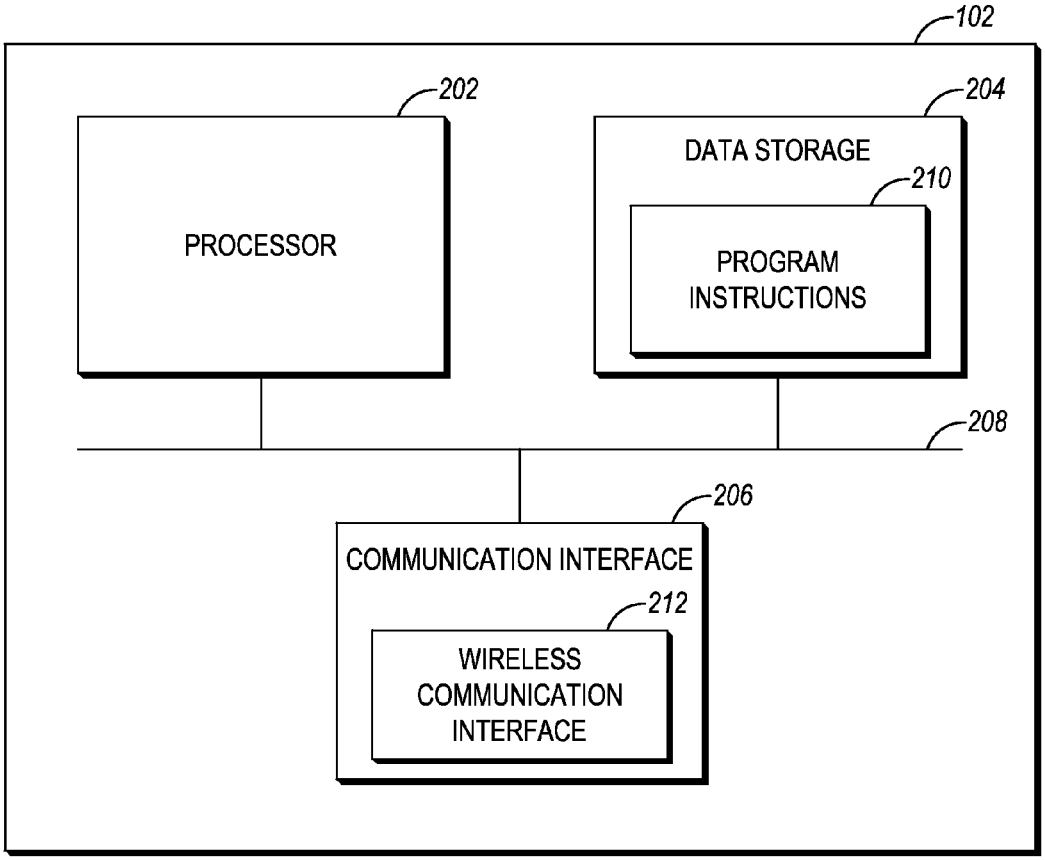
102
202
PROCESSOR
204
DATA STORAGE
210
PROGRAM INSTRUCTIONS
208
206
COMMUNICATION INTERFACE
212
WIRELESS COMMUNICATION INTERFACE

FIG. 2

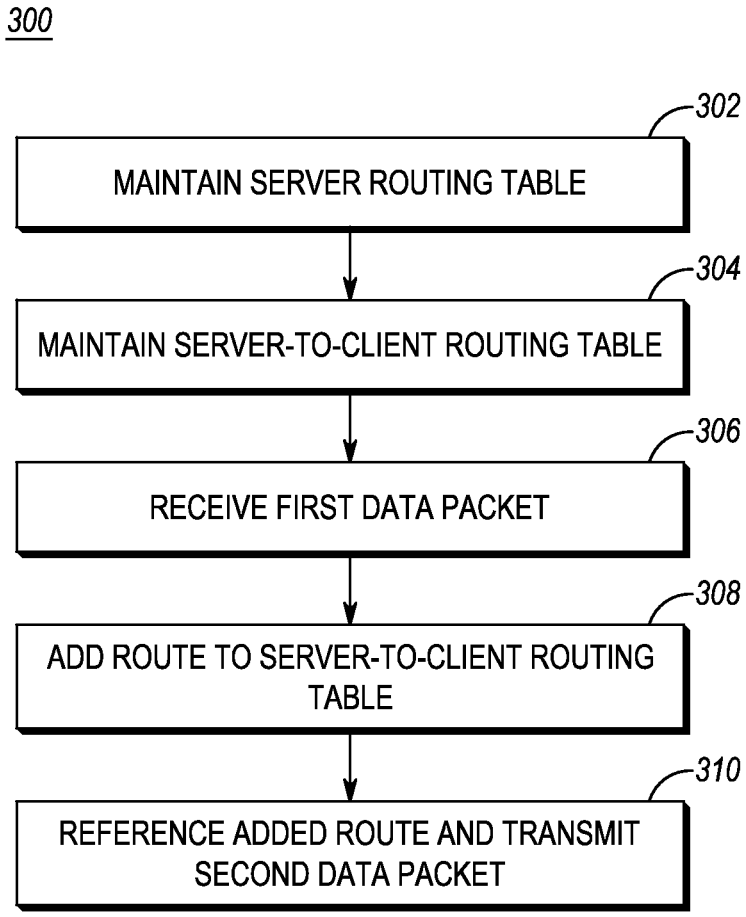
300
302
MAINTAIN SERVER ROUTING TABLE
304
MAINTAIN SERVER-TO-CLIENT ROUTING TABLE
306
RECEIVE FIRST DATA PACKET
308
ADD ROUTE TO SERVER-TO-CLIENT ROUTING TABLE
310
REFERENCE ADDED ROUTE AND TRANSMIT SECOND DATA PACKET

FIG. 3

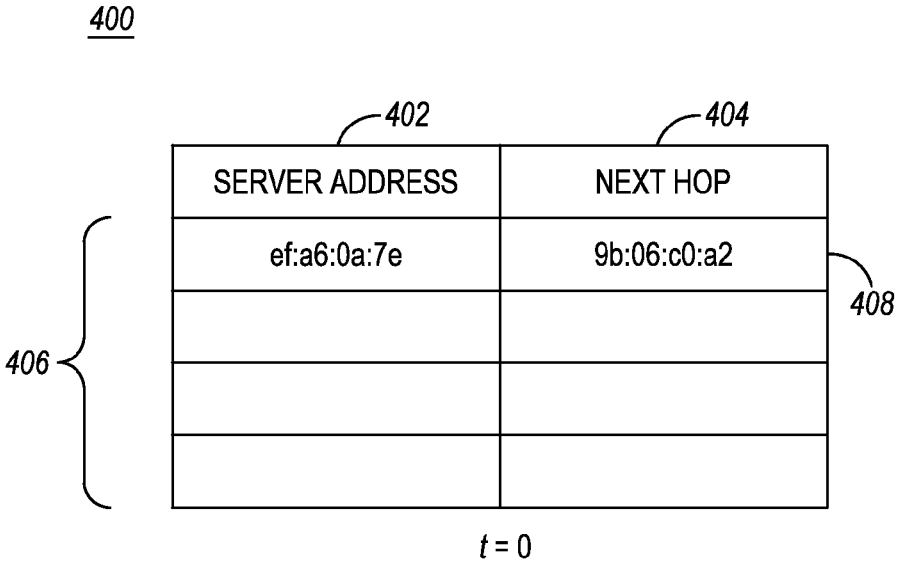
400
402
404
SERVER ADDRESS
NEXT HOP
ef:a6:0a:7e
9b:06:c0:a2
408
406
t = 0

FIG. 4

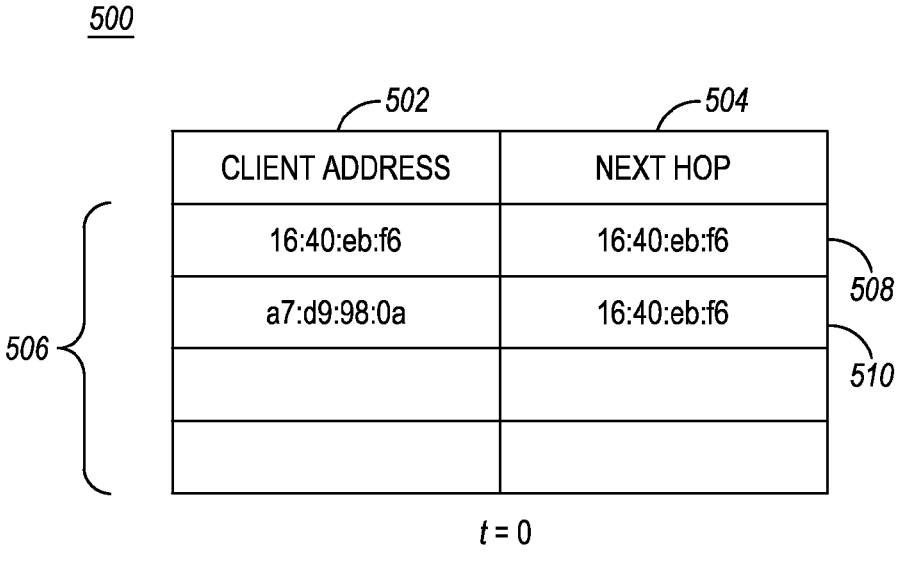
500
502
504
CLIENT ADDRESS
NEXT HOP
16:40:eb:f6
16:40:eb:f6
508
a7:d9:98:0a
16:40:eb:f6
510
506
t = 0

FIG. 5

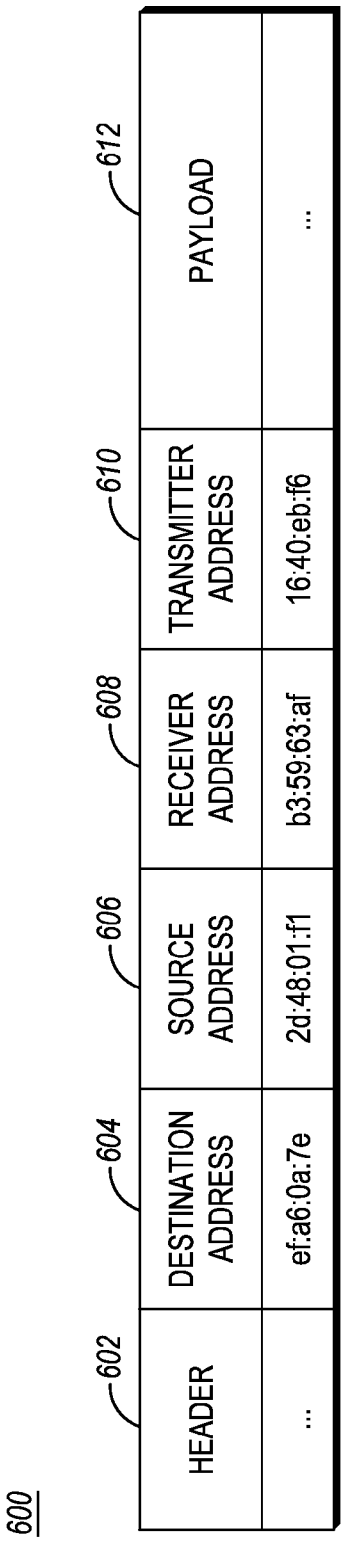
600
602
HEADER
...
604
DESTINATION ADDRESS
ef:a6:0a:7e
606
SOURCE ADDRESS
2d:48:01:f1
608
RECEIVER ADDRESS
b3:59:63:af
610
TRANSMITTER ADDRESS
16:40:eb:f6
612
PAYLOAD
...

FIG. 6

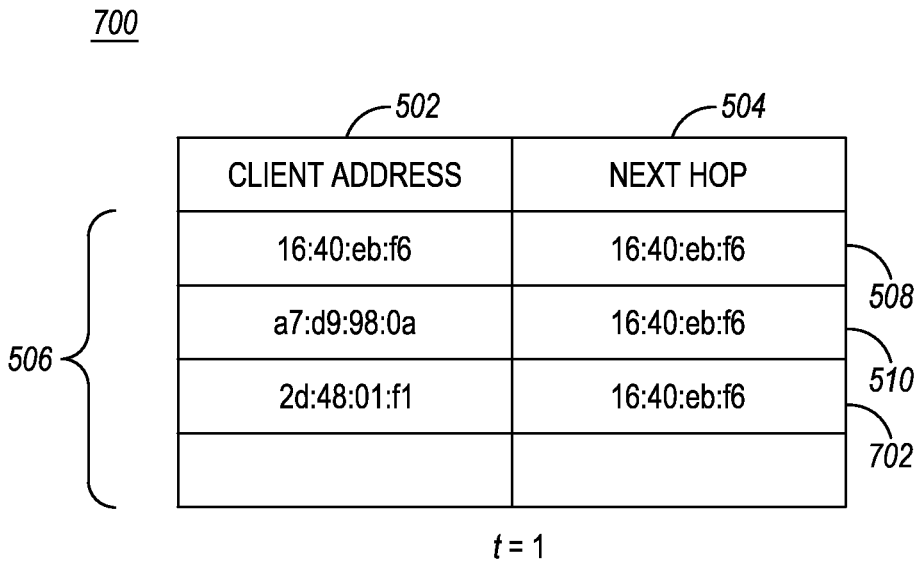
700
502
504
CLIENT ADDRESS
NEXT HOP
16:40:eb:f6
16:40:eb:f6
a7:d9:98:0a
16:40:eb:f6
2d:48:01:f1
16:40:eb:f6
506
508
510
702
t = 1

FIG. 7

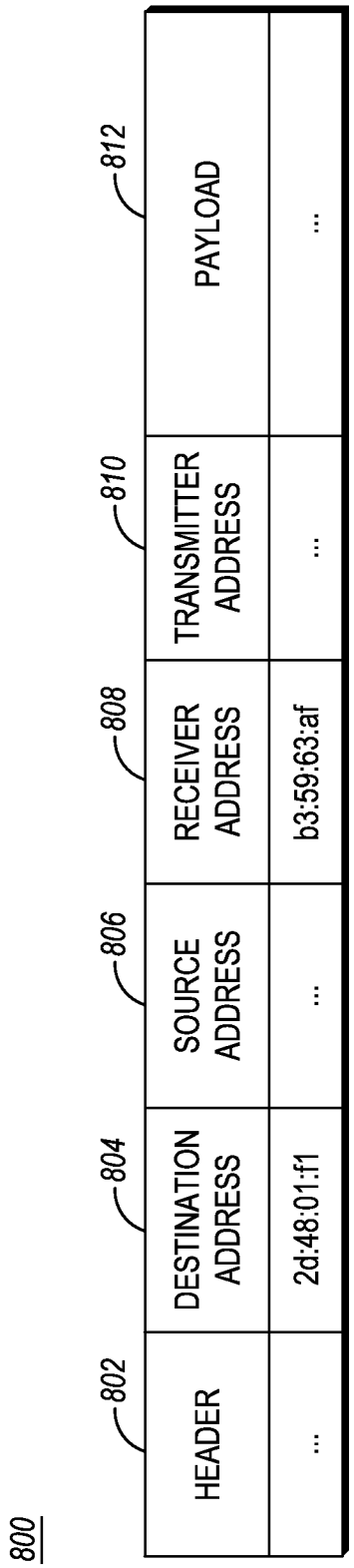
800
802
HEADER
...
804
DESTINATION ADDRESS
2d:48:01:f1
806
SOURCE ADDRESS
...
808
RECEIVER ADDRESS
b3:59:63:af
810
TRANSMITTER ADDRESS
...
812
PAYLOAD
...

FIG. 8

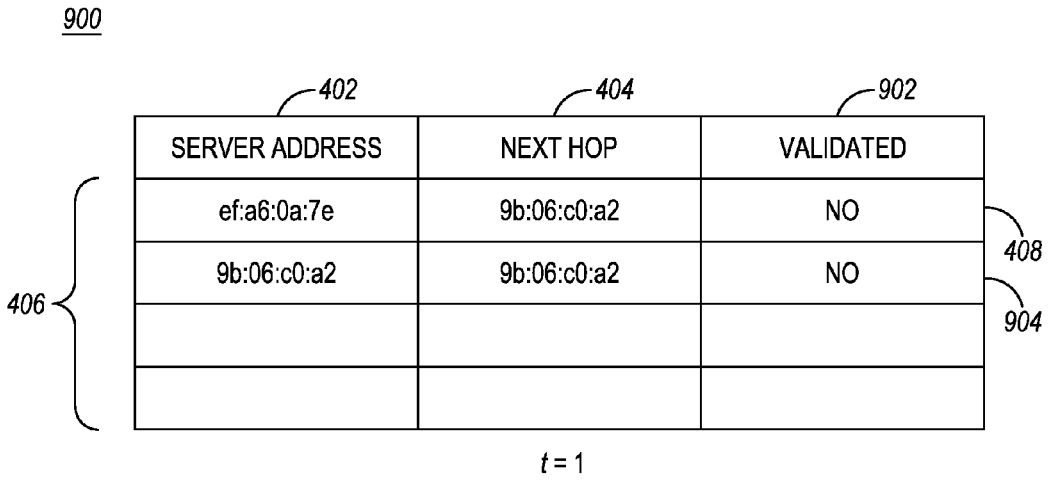
900
402
404
902
SERVER ADDRESS
NEXT HOP
VALIDATED
ef:a6:0a:7e
9b:06:c0:a2
NO
9b:06:c0:a2
9b:06:c0:a2
NO
406
408
904
t = 1

FIG. 9

METHODS AND SYSTEMS FOR MAINTAINING ROUTING TABLES IN AN AD-HOC WIRELESS NETWORK

BACKGROUND OF THE INVENTION

Wireless-communication devices (hereinafter "nodes") such as cell phones, smart phones, and mobile Wi-Fi hotspots are generally configured with the ability to communicate with other network entities via a wireless network. Well known examples of wireless-communication protocols according to which such wireless networks operate include relatively long-range wireless-communication protocols (e.g., Global System for Mobile Communications (GSM), Long Term Evolution (LTE), and the like), relatively short-range wireless-communication protocols (e.g., Wi-Fi and the like), and/or one or more land mobile radio (LMR) protocols (e.g., European Telecommunications Standards Institute Digital Mobile Radio (ETSI-DMR), Terrestrial Trunked Radio (TETRA), APCO Project 25 (P25), Digital Mobile Radio (DMR), and the like), among numerous other examples.

Nodes in an infrastructure-based wireless network typically communicate over an air interface with a network-dedicated base station such as a base transceiver station (BTS), an eNodeB, a wireless access point, and/or a Wi-Fi router (among other examples). The base station is generally responsible for relaying communication between nodes and/or between other networks (such as the Internet). Respective nodes in an infrastructure-based wireless network typically do not communicate directly with other nodes over an air interface.

An ad-hoc wireless network, in contrast, typically does not include a dedicated base station for relaying communication. Rather, each node in the network functions to relay communication between nodes in the network. A respective node will typically communicate directly with nodes that are within wireless-communication range of the respective node, and will otherwise rely on intermediate nodes to relay communication with network nodes that are not within range of the respective node. Moreover, some nodes can function (often according to various device modes) in both infrastructure-based wireless networks and ad-hoc wireless networks, as is known to those having skill in the relevant art.

The data throughput of an ad-hoc wireless network is typically lower than that of a wired network, and the topology of an ad-hoc wireless network will typically change more frequently than the topology of a wired network. Existing routing protocols are not suitable for ad-hoc wireless networks at least because of their relatively high amount of overhead and their inability to accommodate frequent changes in network topology. Accordingly, for at least these reasons, there is a need for methods and systems for maintaining routing tables in an ad-hoc wireless network.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views, together with the detailed description below, are incorporated in and form part of the specification, and serve to further illustrate embodiments of concepts that include the claimed invention, and explain various principles and advantages of those embodiments.

FIG. **1** depicts an example ad-hoc wireless network of nodes, in accordance with at least one embodiment.

FIG. **2** depicts structural elements of an example node, in accordance with at least one embodiment.

FIG. **3** depicts a flowchart of an example process carried out by a first node in an ad-hoc wireless network of nodes, in accordance with at least one embodiment.

FIG. **4** depicts a first example server routing table, in accordance with at least one embodiment.

FIG. **5** depicts a first example server-to-client routing table, in accordance with at least one embodiment.

FIG. **6** depicts a first example data packet, in accordance with at least one embodiment.

FIG. **7** depicts a second example server-to-client routing table, in accordance with at least one embodiment.

FIG. **8** depicts a second example data packet, in accordance with at least one embodiment.

FIG. **9** depicts a second example server routing table, in accordance with at least one embodiment.

Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

The apparatus and method components have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments of the present invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

DETAILED DESCRIPTION OF THE INVENTION

Described herein are methods and systems for maintaining routing tables in an ad-hoc wireless network. At least one embodiment takes the form of a process carried out by a first node in an ad-hoc wireless network of nodes. The first node has a first network address and the nodes in the ad-hoc wireless network exchange data packets that have respective source and destination addresses. The first node maintains a server routing table of server routes to server nodes in the network, and maintains a server-to-client routing table of server-to-client routes from server nodes in the network to client nodes in the network. Each server route includes a server address and an associated next hop, and each server-to-client route includes a client address and an associated next hop. The first node receives a first data packet from a second node that has a second network address. The first data packet has a third network address as the source address and a fourth network address as the destination address. The first node determines that the server routing table (i) contains a stored server route that includes the fourth network address as the server address and (ii) does not contain a server route that includes the third network address as the server address. In response to making this determination, the first node adds a server-to-client route to the server-to-client routing table. The added server-to-client route includes the third network address as the client address and the second network address as the associated next hop. The first node receives a second data packet that has the third network address as the destination address, and responsively references the added server-to-client route in the server-to-client routing table and accordingly transmits the second data packet to the second node at the second network address.

At least one embodiment takes the form of a first node that includes a wireless-communication interface, a processor, and data storage containing instructions executable by the processor for causing the first node to carry out at least the functions described in the preceding paragraph. Moreover, any of the variations and permutations that are described in the ensuing paragraphs and anywhere else in this disclosure can be implemented with respect to any embodiments, including with respect to any method embodiments and with respect to any system embodiments. Furthermore, this flexibility and cross-applicability of embodiments is present in spite of the use of slightly different language (e.g., process, method, steps, functions, set of functions, and the like) to describe and/or characterize such embodiments.

In at least one embodiment, the first node transmits the first data packet according to the stored server route.

In at least one embodiment, the first node receives a first beacon from an advertising node (where an advertising node is defined as a node that transmits such a beacon), where the first beacon identifies the fourth network address as being a server address, and responsively adds the stored server route to the server routing table. Among other possibilities, a beacon could be a standard IEEE 802.11 Beacon Frame, and 802.11 Probe Response Frame, or any other broadcast or multicast message that contains service-availability information, which may be used, at least in part, by nodes to identify server addresses, thus enabling such nodes to distinguish between server nodes and other nodes (e.g., client nodes) in the ad-hoc wireless network.

In at least one embodiment, maintaining the server routing table includes maintaining security indicators of whether or not the respective server routes in the server routing table are validated as having been received from a trusted node. In at least one such embodiment, the first node conditions the transmitting of the first data packet according to the stored server route on having first confirmed that the stored server route is validated.

In at least one embodiment, the first node requests a validation of the stored server route from the advertising node. The first node receives the validation from the advertising node and responsively updates the security indicator associated with the stored server route to indicate that the stored server route is validated.

In at least one embodiment, the first node requests the validation of the stored server route in response to determining that the first beacon does not indicate that the stored server route is validated.

In at least one embodiment, the first node requests the validation of the stored server route in response to receiving from the second node a server-route-validation request that pertains to the fourth network address. In at least one such embodiment, the first node transmits to the second node a server-route-validation response that indicates that the stored server route is validated.

In at least one embodiment, the first node establishes a security association with the advertising node prior to requesting the validation of the stored server route from that node.

In at least one embodiment, the advertising node is a server node that has the fourth network address.

In at least one embodiment, the advertising node is an intermediate node between the first node and a server node that has the fourth network address.

In at least one embodiment, the advertising node is a trusted node to the first node when the first node receives the first beacon from the advertising node. In at least one such embodiment, the first node determines that the first beacon indicates that the stored server route is validated, and responsively updates the associated security indicator to indicate that the stored server route is validated.

In at least one embodiment, the first node, after receiving the first beacon, transmits a second beacon that identifies the fourth network address as being a server address and that includes a next hop associated with the fourth network address.

In at least one embodiment, the first beacon includes a first set of advertised-service data, and the first node includes the first set of advertised-service data in the second beacon. In at least one such embodiment, the first node includes at least one additional, previously received set of advertised-service data in the second beacon. In at least one embodiment, the second beacon indicates that the stored server route is validated.

In at least one embodiment, the fourth network address is a server address of an access-point node that has connectivity to both the ad-hoc wireless network and an infrastructure network. In at least one such embodiment, the first beacon includes advertised-service data pertaining to at least one infrastructure-network service available on the ad-hoc wireless network via the access-point node. In at least one further such embodiment, the access-point node advertises, on the infrastructure network, at least one ad-hoc-wireless-network service available on the infrastructure network via the access-point node. In at least one embodiment, the access-point node functions as a translating node between an infrastructure-network service-advertisement format and an ad-hoc-wireless-network service-advertisement format.

Before proceeding with this detailed description, it is noted that the entities, connections, arrangements, and the like that are depicted in—and described in connection with—the various figures are presented by way of example and not by way of limitation. As such, any and all statements or other indications as to what a particular figure "depicts," what a particular element or entity in a particular figure "is" or "has," and any and all similar statements—that may in isolation and out of context be read as absolute and therefore limiting—can only properly be read as being constructively preceded by a clause such as "In at least one embodiment, . . . " And it is for reasons akin to brevity and clarity of presentation that this implied leading clause is not repeated ad nauseum in this detailed description.

FIG. **1** depicts an example ad-hoc wireless network of nodes, in accordance with at least one embodiment. As shown, example ad-hoc wireless network **100** includes first through seventh nodes **102-114**, each of which is communicatively connected with one or more of the other nodes in the network **100** via one or more air interfaces **118-130**. Network **100** could take the form of a mobile ad-hoc network (MANET), a wireless mesh network, and/or a wireless sensor network, among other examples. It should be understood that network **100** may have a different topology than that shown in FIG. **1**, and that network **100** may include different and/or additional nodes, air interfaces, and the like.

By way of example, first node **102** is described more fully below in connection with FIG. **2**, though in general any one or more of nodes **102-114** may take the form of respective two-way radios, mobile phones, smart phones, tablet computers, notebook computers, portable media players, loudspeakers, televisions, smart glasses, lapel-worn cameras and/or microphones, surveillance cameras, unmanned aerial vehicles (UAVs), and/or any other devices capable of ad-hoc wireless communication, among numerous other possibilities.

In at least one embodiment, one or more of nodes **102-114** exchange data packets that have respective source and destination addresses. The addresses could take the form of respective media access control (MAC) addresses and/or Internet protocol (IP) addresses, as examples. Those of skill in the art will appreciate that one or more nodes (in addition to first node **102**) may have respective network addresses. For example, in the embodiment illustrated in FIG. **1**, each of first through seventh nodes **102-114** has a respective network address; thus, first node **102** has first network address b3:59:63:af, second node **104** has second network address 16:40:eb:f6, third node **106** has third network address 2d:48:01:f1, fourth node **108** has fourth network address ef:a6:0a:7e, fifth node **110** has fifth network address 9b:06:c0:a2, sixth node **112** has sixth network address a7:d9:98:0a, and seventh node **114** has seventh network address 55:a6:51:a1.

Air interfaces **118-130** may take the form of respective radio-frequency (RF) air-interface links between directly-connected nodes (i.e., nodes that are each within each other's wireless-communication range). The air interfaces may comply with one or more standards (e.g., Wi-Fi, TETRA, etc.) discussed above, among numerous other possibilities. One or more nodes in network **100** may function to relay communication between other nodes that are not within each other's wireless-communication range, but that are within the wireless-communication range of one or more relaying nodes.

In various different embodiments, a given node in network **100** may function as a gateway to one or more other networks. By way of example, in the embodiment illustrated in FIG. **1**, seventh node **114** is connected to a network **116** via a communication link **132**, and may function to relay communication between network **116** and other nodes in ad-hoc wireless network **100**, thus allowing other nodes in ad-hoc wireless network **100** to communicate with entities outside of the ad-hoc wireless network. Network **116** could be or include a circuit-switched network (such as the Public Switched Telephone Network (PSTN)), a packet-switched network (such as the Internet), and/or any other suitable network or networks. Communication link **132** could include one or more communication devices, networks, connections, switches, bridges, routers, and the like, and could make use of wired and/or wireless forms of communication. Moreover, one or more communication links instead of and/or in addition to communication link **132** could be present.

FIG. **2** depicts structural elements of an example node, in accordance with at least one embodiment. In the depicted embodiment, first node **102** includes a processor **202**, data storage **204**, and a communication interface **206**, all of which are interconnected via a system bus **208**. Those having skill in the art will appreciate that first node **102** could have additional and/or different components, and perhaps a different arrangement of components, among many other possible variations. Moreover, while depicted and described as being interconnected via a system bus **208**, the various components of first node **102** could be interconnected via another suitable communication link, network, or the like. Additionally, in various different embodiments, first node **102** may take the form of a single device or a combination of devices, as deemed suitable by those in the art.

Processor **202** may include one or more processors of any type deemed suitable by those of skill in the art, some examples including a microprocessor and a dedicated digital signal processor (DSP). Data storage **204** may take the form of any non-transitory computer-readable medium or combination of such media, some examples including flash memory, read-only memory (ROM), and random-access memory (RAM) to name but a few, as any one or more types of non-transitory data-storage technology deemed suitable by those of skill in the relevant art could be used.

As depicted in FIG. **2**, data storage **204** contains program instructions **210** executable by processor **202** for carrying out various functions, though data storage **204** may contain different and/or additional data. In an embodiment in which first node **102** is configured to carry out one or more processes and/or functions (such as the processes and functions described below with reference to FIG. **3**), program instructions **210** are executable by processor **202** for carrying out those functions. In instances where other entities described herein (such as other nodes in network **100**) have a structure similar to that depicted in and described in connection with FIG. **2**, the respective program instructions **210** stored by the respective data storages **204** of those respective devices are executable by their respective processors **202** to carry out functions respectively performed by those devices.

Communication interface **206** (which, in the depicted embodiment, includes a wireless-communication interface **212**) may include any necessary hardware (e.g., chipsets, antennas, Ethernet cards, and the like), any necessary firmware, and/or any necessary software for conducting one or more forms of communication. Wireless-communication interface **212** may be configured to communicate according to one or more of the wireless-communication types and/or protocols mentioned above, and/or one or more other types and/or protocols deemed suitable by those having skill in the relevant art for a given implementation or a given context. Communication interface **206** could include a wired-communication interface, which may be configured to communicate according to one or more communication types and/or protocols such as Ethernet, Universal Serial Bus (USB), and the like, and/or one or more other types and/or protocols deemed suitable by those having skill in the relevant art for a given implementation or context. Those having skill in the relevant art will appreciate that communication interface **206** may contain different and/or additional interfaces.

Those having skill in the relevant art will further appreciate that any one or more entities within network **100** (such as any one or more other nodes), any entities connected to network **100** (e.g., via node **114**), and/or any other network entities could take a form similar to that of first node **102** as depicted in FIG. **2**. As stated, first node **102** may be a single device located within network **100**, or may take the form of a distributed computing device whose functionality is divided across multiple devices. And certainly other implementations are possible.

FIG. **3** depicts a flowchart of an example process carried out by a first node in an ad-hoc wireless network of nodes, in accordance with at least one embodiment. In particular, FIG. **3** depicts an example process **300** that is described herein as being carried out by first node **102**, though this is by way of example and not limitation, as the process **300** could be carried out by any device or devices deemed suitable by those of skill in the relevant art for a given implementation or context. As described above, first node **102** has first network address b3:59:63:af, and the various nodes **102-114** in network **100** exchange packets that have respective source and destination addresses. It is further noted that one or more of the nodes **102-114** may function as servers in the network **100** (with respect to one or more services such as the Domain Name Service (DNS) by way

of example), and that one or more of the nodes **102-114** may function as clients in the network **100**, and furthermore that one or more of the nodes **102-114** may function as both a server and a client in the network **100**.

At step **302**, first node **102** maintains what is referred to herein as a "server routing table," several examples of which are described below and depicted in FIGS. **4** and **9**. The server routing table is a table of routes to server nodes in network **100**: such routes are referred to in this disclosure as "server routes," and each server route includes a network address of a server node in network **100** (i.e., "a server address") and an associated next hop.

At step **304**, first node **102** maintains another routing table that is separate and distinct from the server routing table that is discussed above in connection with step **302**. This additional routing table is referred to herein as a "server-to-client routing table," several examples of which are described below and depicted in FIGS. **5** and **7**. The server-to-client routing table is a table of routes from server nodes in network **100** to client nodes in network **100**: such routes are referred to in this disclosure as "server-to-client routes," and each server-to-client route includes a network address of a client node in network **100** (i.e., "a client address") and an associated next hop.

At step **306**, first node **102** receives a first data packet from second node **104**, which as described above has the second network address 16:40:eb:f6. In this example, the first data packet has the third network address 2d:48:01:f1 (of third node **106**) as the source address and the fourth network address ef:a6:0a:7e (of fourth node **108**) as the destination address. An example first data packet is depicted in and described in connection with FIG. **6**.

Responsive to receiving the first data packet, first node **102** checks whether its server routing table contains a server route to the third network address 2d:48:01:f1 (of third node **106**), and also whether its server routing table contains a server route to the fourth network address ef:a6:0a:7e (of fourth node **108**).

At step **308**, first node **102** determines that (i) its server routing table does contain a stored server route to the fourth network address ef:a6:0a:7e (of fourth node **108**) (i.e., a stored server route that includes the fourth network address ef:a6:0a:7e (of fourth node **108**) as the server address of that server route) and (ii) its server routing table does not contain a server route to the third network address 2d:48:01:f1 (of third node **106**) (i.e., a server route that includes the third network address 2d:48:01:f1 (of third node **106**) as the server address of that server route), and responsively adds a server-to-client route to its server-to-client routing table. The added server-to-client route includes the third network address 2d:48:01:f1 (of third node **106**) as the client address of that server-to-client route and the second network address 16:40:eb:f6 (of second node **104**) as the associated next hop.

At step **310**, first node **102** receives a second data packet, which has the third network address 2d:48:01:f1 (of third node **106**) as the destination address, and responsively references the server-to-client route that first node **102** added to its server-to-client routing table at step **308**, and first node **102** accordingly transmits the second data packet to second node **104** at the second network address 16:40:eb:f6,which is listed as the next hop that is associated with the client address 2d:48:01:f1 (i.e., the third network address) in the server-to-client routing table of first node **102**.

The next portion of this disclosure includes descriptions of FIGS. **4-9**, which depict examples of some of the various routing tables and packets that are mentioned in the above description of the example process **300** of FIG. **3**.

FIG. **4** depicts a first example server routing table, in accordance with at least one embodiment. In particular, FIG. **4** depicts an example server routing table **400** that may be stored (and being maintained) by first node **102** at a point in time that is arbitrarily denoted t=0 in FIG. **4**. As shown, server routing table **400** includes a set **406** of server routes to server nodes in network **100**. At a given time, set **406** could be empty (if, e.g., first node **102** has yet to receive any routing information with which to populate the set) or could include one or more server routes. Each server route in server routing table **400** includes a server address **402** and an associated next hop **404**, though in at least one embodiment, one or more of the server routes includes additional information such as respective route metrics (e.g., costs), route flags, and/or security indicators, among numerous other examples that could be listed here.

As can be seen in FIG. **4**, at time t =**0**, server routing table **400** of first node **102** contains a single server route **408**, which lists the fourth network address ef:a6:0a:7e (of fourth node **108**) as the server address of that server route and the fifth network address 9b:06:c0:a2 (of fifth node **110**) as the next hop associated with that server route. Thus, FIG. **4** corresponds to the state of the server routing table of first node **102** at the time that first node **102** carries out at least part of the above-described step **308**; i.e., at the time that first node **102** determines that (i) its server routing table does contain a stored server route to the fourth network address ef:a6:0a:7e (of fourth node **108**) (i.e., the stored server route **408**) and (ii) its server routing table does not contain a server route to the third network address 2d:48:01:f1 (of third node **106**).

FIG. **5** depicts a first example server-to-client routing table, in accordance with at least one embodiment. In particular, FIG. **5** depicts an example server-to-client routing table **500** that may be stored (and being maintained) by first node **102** at time t=0. As shown, server-to-client routing table **500** includes a set **506** of server-to-client routes from server nodes in network **100** to client nodes in network **100**. As with set **406** of server routes, set **506** of server-to-client routes may include zero or more server-to-client routes. Each server-to-client route in server-to-client routing table **500** includes a server address **502** and an associated next hop **504**, though one or more of the server-to-client routes could include additional information (such as the additional information described above with reference to FIG. **4**).

As can be seen in FIG. **5**, at time t=0, server-to-client routing table **500** of first node **102** contains two client-to-server routes **508** and **510**. The server-to-client route **508** lists the second network address 16:40:eb:f6 (of second node **104**) as the client address of that server-to-client route and also lists the second network address 16:40:eb:f6 (of second node **104**) as the next hop associated with that server-to-client route. These two values are the same because first node **102** and second node **104** are only a single hop (communication link **118**) from one another. The server-to-client route **510** lists the sixth network address a7:d9:98:0a (of sixth node **112**) as the client address of that server-to-client route and the second network address 16:40:eb:f6 (of second node **104**) as the next hop associated with that server-to-client route. Thus, FIG. **5** corresponds to the state of the server-to-client routing table of first node **102** prior to the time that first node **102** completes the above-described step **308**; i.e., prior to the time that first node **102** adds to its server-to-client table a server-to-client route that includes the third network address 2d:48:01:f1 (of third node **106**) as

the client address of that server-to-client route and the second network address 16:40:eb:f6 (of second node **104**) as the associated next hop.

FIG. **6** depicts a first example data packet, in accordance with at least one embodiment. In particular, FIG. **6** depicts a first example data packet **600**, which corresponds to the first example data packet that first node **102** receives from second node **104** at the above-described step **306**. The first data packet **600** includes a header **602**, a destination address **604**, a source address **606**, a receiver address **608**, a transmitter address **610**, and a payload **612**. Data packet **600** could take the form of a frame, a datagram, a segment, and/or any other type of data packet, as examples.

Moreover, header **602** may include metadata relating to data packet **600**, such as a packet type, a packet priority, etc. For example, header could identify the data packet as a beacon, a service advertisement, a route-validation request, and/or a route-validation response, among numerous other possible examples. Destination address **604** may indicate the network address of a destination node that is to ultimately receive data packet **600**, and source address **606** may indicate the network address of a source node that initially created and transmitted data packet **600**. Receiver address **608** may indicate the address of a directly-connected receiver node that is to receive data packet **600**, and transmitter address **610** may indicate the address of a directly-connected transmitter node that transmitted data packet **600**.

Consistent with the above description of step **306**, the first data packet **600** has the third network address 2d:48:01:f1 (of third node **106**) as its source address **606** and the fourth network address ef:a6:0a:7e (of fourth node **108**) as its destination address **604**. Moreover, the first data packet **600** has the first network address b3:59:63:af (of first node **102**) as its receiver address **608** and the second network address 16:40:eb:f6 (of second node **104**) as its transmitter address **610**.

Those of skill in the art will appreciate that first data packet **600** may take other forms and could include different and/or additional data. For example, in at least one embodiment, first data packet **600** includes at least one of a sequence-control field and a frame-check-sequence field. Other data packets exchanged by nodes **102-114** could take a form similar to that of first data packet **600**.

In general, with respect to both FIG. **6** and FIG. **8**, the order and/or arrangement of the various depicted packet elements (including the various addresses (i.e., source, destination, transmitter, receiver)) is not intended to be limiting, and in fact the addresses may appear in any order. Further, in at least one embodiment, all of these addresses pertain to the same layer of the OSI stack; for example, they may all be 802.11 MAC addresses. In the depicted embodiment, data packets **600** and **800** are example MAC-layer frames. In at least one embodiment, the transmitter and receiver addresses are MAC-layer addresses and the source and destination addresses are layer-3 (i.e., network-layer) (e.g., IP) addresses. In embodiments in which the source and destination addresses are layer-3 addresses, the source and destination addresses may be contained in a layer-3 packet contained in the payload (**612** or **812**) of the packet (**600** or **800**, respectively). In at least one such embodiment, the receiver address **608** and the transmitter address **610** are each a layer-2 (i.e., MAC-layer) address; that is to say, in at least one such embodiment, the MAC-layer source address is treated as the transmitter address **610** and the MAC-layer destination address is treated as the receiver address **608**, while the network-layer source address is treated as the source address **606** and the network-layer destination address is treated as the destination address **604**. In still another embodiment, all four of the destination address **604**, the source address **606**, the receiver address **608**, and the transmitter address **610** are network-layer addresses, and data packet **600** is a network-layer packet. And certainly numerous other example implementations could be listed here, and all examples explained using the reference numerals of FIG. **6** could just as well have been explained using the reference numerals of FIG. **8**.

In yet another embodiment all four addresses are layer 3 addresses, and data packet **600** depicts a network layer packet.

FIG. **7** depicts a second example server-to-client routing table, in accordance with at least one embodiment. In particular, FIG. **7** depicts an example server-to-client routing table **700** that, for the most part, matches the example server-to-client routing table **500** of FIG. **5**. Indeed, while the server-to-client routing table **500** is a depiction of the server-to-client routing table **500** of first node **102** at time t=0, the server-to-client routing table **700** of first node **102** at time t=1. Like the server-to-client routing table **500**, server-to-client routing table includes the above-described server-to-client routes **508** and **510**. The server-to-client routing table **700** also includes an additional server-to-client route **702**, which lists the third network address 2d:48:01:f1 (of third node **106**) as the client address of that server-to-client route and the second network address 16:40:eb:f6 (of second node **104**) as the associated next hop. As such, the server-to-client routing table **700** corresponds to the state of the server-to-client routing table of first node **102** after first node **102** has completed the above-described step **308** (of adding that particular server-to-client route to the server-to-client table).

FIG. **8** depicts a second example data packet, in accordance with at least one embodiment. In particular, FIG. **8** depicts a second example data packet **800**, which corresponds to the second example data packet that first node **102** receives at the above-described step **310**. It is noted that, as described above, first node **102** also transmits the second data packet at step **310**; those of skill in the art will understand that this receive-and-forward sequence does not mean forwarding the received packet without any alterations; indeed, first node **102** receives and forwards the payload of the second packet **800** at least in part by changing the receiver address to whichever next hop first node **102** chooses for that routing action, and further by changing the transmitter address to the first network address b3:59:63:af (of first node **102**).

The second data packet **800** has a header **802**, a destination address **804**, a source address **806**, a receiver address **808**, a transmitter address **810**, and a payload **812**. The second data packet **800** of FIG. **8** is similar in a number of ways to the first data packet **600** of FIG. **6**, and thus is not described in as much detail. As can be seen in FIG. **8**, and consistent with the description of the second data packet that is referenced above in the description of step **310**, the second data packet **800** has the third network address 2d:48:01:f1 (of third node **106**) as its destination address **804**. And consistent with the fact that first node **102** is the recipient in step **310** of the second data packet, the second data packet **800** of FIG. **8** has the first network address b3:59:63:af (of first node **102**) as its receiver address **808**.

FIG. **9** depicts a second example server routing table, in accordance with at least one embodiment. In particular, FIG. **9** depicts a server routing table **900** that includes all aspects of the server routing table **400** of FIG. **4**, and that further includes a "Validated" column **902** and an additional server

route **904**. The server table **400** of FIG. **4** corresponds to the above-referenced example time t=0, while the server table **900** of FIG. **9** corresponds to the above-referenced example time t=1. It is noted that, in at least one embodiment, the first node **102** received a beacon (between time t=0 and time t=1) from the fifth node **110**, where that beacon listed the fifth network address 9b:06:c0:a2 (of fifth node **110**) as being a server address. And certainly numerous other example fact patterns could be listed here that could result in the first node **102** storing the server routing table **400** of FIG. **4** at time t=0 and storing the server routing table **900** of FIG. **9** at time t=1, which could be any arbitrary amount of time after time t=0.

The server route **904** lists the fifth network address 9b:06:c0:a2 (of fifth node **110**) as the server address for server route **904**, the fifth network address 9b:06:c0:a2 (of fifth node **110**) as the associated next hop for that server route **904**, and an indication that server route **904** is not (or has not yet been) validated. As used herein, "validated" means "validated as having been received from a trusted node." The server route **408** also has an indication that it is not (or has not yet been) validated.

Some additional embodiments are further described below, using the reference numerals of FIGS. **1-9** as illustrative examples.

In at least one embodiment, first node **102** transmits first data packet **600** according to the stored server route **408**; i.e., first node **102** transmits first data packet **600** to the fifth network address 9b:06:c0:a2 (of fifth node **110**), which is the associated next hop of the stored server route **408**.

In an embodiment, first node **102** receives, from an advertising node, a first beacon that identifies the network address of fourth node **108** as being a server address, and may responsively add server route **408** to server routing table **400**. The advertising node could be an intermediate node (e.g., fifth node **110**) between first node **102** and fourth node **108**. In other embodiments, the advertising node could instead be a server node (e.g., fourth node **108**) that itself has the network address identified in the first beacon as being a server address. After receiving the first beacon, first node **102** may transmit (e.g., to second node **104**) a second beacon that identifies the fourth network address ef:a6:0a:7e (of fourth node **108**) as being a server address. The second beacon may include a next hop (e.g., the network address of first node **102**) associated with the network address of fourth node **108**.

The first beacon may include a first set of advertised-service data, and first node **102** may include that set of advertised-service data in the second beacon. First node **102** may also include at least one additional, previously received set of advertised-service data in the second beacon (e.g., advertised-service data received via a third beacon). Any given set of advertised-service data may include a list of services, some examples of which include the above-mentioned DNS, an incident-portal service (which may be a web service (e.g., a dashboard) regarding public-safety incident status, an incident-presence server (which may function as a registrar regarding people and/or devices present at a scene of a given public-safety incident), a multimedia group manager (which may function similar to a presence server for talkgroups), and a context server (which may amalgamate numerous incident-related data points regarding status and well-being of personnel and/or equipment associated with a given public-safety incident), and/or one or more other types of services deemed suitable by those of skill in the relevant art.

First node **102** may determine that the first beacon does not indicate that stored server route **408** is validated, and may responsively request the validation of stored server route **408**. Alternatively, first node **102** may determine that the first beacon does indicate that stored server route **408** is validated, and may responsively update the security indicator **902** associated with stored server route **408** to indicate that stored server route **408** is validated. In at least one embodiment, fifth node **110** (the advertising node) is a trusted node to first node **102** when first node **102** receives the first beacon from fifth node **110**. Fifth node **110** may become a trusted node by, for example, first node **102** establishing a security association with fifth node **110**. In an embodiment, the second beacon (transmitted by first node **102**) indicates that the stored server route is validated.

In at least one embodiment, first node **102** requests the validation of stored server route **408** in response to receiving from second node **104** a server-route-validation request that pertains to the fourth network address ef:a6:0a:7e (of fourth node **108**). First node **102** transmits to second node **104** a server-route-validation response that indicates that the stored server route is validated. In at least one embodiment, first node **102** establishes a security association with fifth node **110** prior to requesting the validation of stored server route **408** from that node.

In an embodiment, fourth node **108** is an access-point node that has connectivity to both ad-hoc wireless network **100** and an infrastructure network (network **116** in this example). The first beacon (transmitted by fifth node **110**, for example) may include advertised-service data pertaining to at least one infrastructure-network service available on ad-hoc wireless network **100** via access-point node **108**. In an embodiment, access-point node **108** advertises, on infrastructure network **116**, at least one ad-hoc-wireless-network service available on infrastructure network **116** via access-point node **108**. Access-point node **108** may function as a translating node between an infrastructure-network service-advertisement format (e.g., DNS-SD) and an ad-hoc-wireless-network service-advertisement format (e.g., IEEE 802.11 beacons containing service advertisement information elements (SAIEs)).

In the foregoing specification, specific embodiments have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present teachings.

The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

Moreover in this document, relational terms such as first and second, top and bottom, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms "comprises," "comprising," "has", "having," "includes", "including," "contains", "containing" or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises, has, includes, contains a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process,

method, article, or apparatus. An element proceeded by "comprises . . . a", "has . . . a", "includes . . . a", "contains . . . a" does not, without more constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises, has, includes, contains the element. The terms "a" and "an" are defined as one or more unless explicitly stated otherwise herein. The terms "substantially", "essentially", "approximately", "about" or any other version thereof, are defined as being close to as understood by one of ordinary skill in the art, and in one non-limiting embodiment the term is defined to be within 10%, in another embodiment within 5%, in another embodiment within 1% and in another embodiment within 0.5%. The term "coupled" as used herein is defined as connected, although not necessarily directly and not necessarily mechanically. A device or structure that is "configured" in a certain way is configured in at least that way, but may also be configured in ways that are not listed.

It will be appreciated that some embodiments may be comprised of one or more generic or specialized processors (or "processing devices") such as microprocessors, digital signal processors, customized processors and field programmable gate arrays (FPGAs) and unique stored program instructions (including both software and firmware) that control the one or more processors to implement, in conjunction with certain non-processor circuits, some, most, or all of the functions of the method and/or apparatus described herein. Alternatively, some or all functions could be implemented by a state machine that has no stored program instructions, or in one or more application specific integrated circuits (ASICs), in which each function or some combinations of certain of the functions are implemented as custom logic. Of course, a combination of the two approaches could be used.

Moreover, an embodiment can be implemented as a computer-readable storage medium having computer readable code stored thereon for programming a computer (e.g., comprising a processor) to perform a method as described and claimed herein. Examples of such computer-readable storage mediums include, but are not limited to, a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a ROM (Read Only Memory), a PROM (Programmable Read Only Memory), an EPROM (Erasable Programmable Read Only Memory), an EEPROM (Electrically Erasable Programmable Read Only Memory) and a Flash memory. Further, it is expected that one of ordinary skill, notwithstanding possibly significant effort and many design choices motivated by, for example, available time, current technology, and economic considerations, when guided by the concepts and principles disclosed herein will be readily capable of generating such software instructions and programs and ICs with minimal experimentation.

The Abstract of the Disclosure is provided to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in various embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

What is claimed is:

1. A method carried out by a first node in an ad-hoc wireless network of nodes that exchange data packets that have respective source and destination addresses, wherein the first node has a first network address, the method comprising:

maintaining a server routing table of server routes to server nodes in the network, wherein each server route includes a server address and an associated next hop;

maintaining a server-to-client routing table of server-to-client routes from server nodes in the network to client nodes in the network, wherein each server-to-client route includes a client address and an associated next hop;

receiving a first data packet from a second node that has a second network address, wherein the first data packet has a third network address as the source address and a fourth network address as the destination address;

determining that the server routing table (i) contains a stored server route that includes the fourth network address as the server address and (ii) does not contain a server route that includes the third network address as the server address, and responsively adding a server-to-client route to the server-to-client routing table, wherein the added server-to-client route includes the third network address as the client address and the second network address as the associated next hop; and

receiving a second data packet that has the third network address as the destination address, and responsively referencing the added server-to-client route in the server-to-client routing table and accordingly transmitting the second data packet to the second node at the second network address.

2. The method of claim **1**, further comprising:

transmitting the first data packet according to the stored server route.

3. The method of claim **2**, further comprising:

receiving from an advertising node a first beacon that identifies the fourth network address as being a server address, and responsively adding the stored server route to the server routing table.

4. The method of claim **3**, wherein:

maintaining the server routing table comprises maintaining security indicators of whether or not the respective server routes in the server routing table are validated as having been received from a trusted node, and

the first node conditions the transmitting of the first data packet according to the stored server route on having first confirmed that the stored server route is validated.

5. The method of claim **4**, further comprising:

requesting a validation of the stored server route from the advertising node; and

receiving the requested validation from the advertising node, and responsively updating the security indicator associated with the stored server route to indicate that the stored server route is validated.

6. The method of claim **5**, wherein the first node requests the validation of the stored server route in response to determining that the first beacon does not indicate that the stored server route is validated.

7. The method of claim **5**, wherein the first node requests the validation of the stored server route in response to

receiving from the second node a server-route-validation request that pertains to the fourth network address, the method further comprising:

transmitting to the second node a server-route-validation response that indicates that the stored server route is validated.

8. The method of claim **5**, further comprising:

establishing a security association with the advertising node prior to requesting the validation of the stored server route from that node.

9. The method of claim **8**, wherein the advertising node is a server node that has the fourth network address.

10. The method of claim **8**, wherein the advertising node is an intermediate node between the first node and a server node that has the fourth network address.

11. The method of claim **4**, wherein the advertising node is a trusted node to the first node when the first node receives the first beacon from the advertising node, the method further comprising:

determining that the first beacon does indicate that the stored server route is validated, and responsively updating the security indicator associated with the stored server route to indicate that the stored server route is validated.

12. The method of claim **3**, further comprising:

after receiving the first beacon, transmitting a second beacon that identifies the fourth network address as being a server address, the second beacon including a next hop associated with the fourth network address.

13. The method of claim **12**, wherein the first beacon includes a first set of advertised-service data, the method further comprising:

including the first set of advertised-service data in the second beacon.

14. The method of claim **13**, further comprising:

including at least one additional, previously received set of advertised-service data in the second beacon.

15. The method of claim **12**, wherein the second beacon indicates that the stored server route is validated.

16. The method of claim **3**, wherein the fourth network address is a server address of an access-point node that has connectivity to both the ad-hoc wireless network and an infrastructure network.

17. The method of claim **16**, wherein the first beacon includes advertised-service data pertaining to at least one infrastructure-network service available on the ad-hoc wireless network via the access-point node.

18. The method of claim **16**, wherein the access-point node advertises, on the infrastructure network, at least one ad-hoc-wireless-network service available on the infrastructure network via the access-point node.

19. The method of claim **16**, wherein the access-point node functions as a translating node between an infrastructure-network service-advertisement format and an ad-hoc-wireless-network service-advertisement format.

20. A first node in an ad-hoc wireless network of nodes that exchange data packets that have respective source and destination addresses, wherein the first node has a first network address, the first node comprising:

a wireless-communication interface;

a processor; and

data storage containing instructions executable by the processor for causing the first node to carry out a set of functions, the set of functions including:

maintaining a server routing table of server routes to server nodes in the network, wherein each server route includes a server address and an associated next hop;

maintaining a server-to-client routing table of server-to-client routes from server nodes in the network to client nodes in the network, wherein each server-to-client route includes a client address and an associated next hop;

receiving a first data packet from a second node that has a second network address, wherein the first data packet has a third network address as the source address and a fourth network address as the destination address;

determining that the server routing table (i) contains a stored server route that includes the fourth network address as the server address and (ii) does not contain a server route that includes the third network address as the server address, and responsively adding a server-to-client route to the server-to-client routing table, wherein the added server-to-client route includes the third network address as the client address and the second network address as the associated next hop; and

receiving a second data packet that has the third network address as the destination address, and responsively referencing the added server-to-client route in the server-to-client routing table and accordingly transmitting the second data packet to the second node at the second network address.

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